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Explosive Line Wave Generators

S. A. Weckert, J. Freundt and S. Stojko

Weapons and Counter Measures Division
Defence Science and Technology Organisation

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ABSTRACT

This report assesses two types of explosive line wave generator which can be used for line initiation of an explosive charge. The two types are a perforated triangle design utilising equal path lengths through the explosive to create a straight detonation wave; and an explosive lens design employing two explosives with different detonation velocities to remove the curvature from the detonation wave. A Cordin high speed camera was used for imaging the detonation wave to assess the degree of curvature produced by each line wave generator. Piezoelectric pins were used for an additional assessment of the explosive lens design.

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PO Box 1500
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Telephone: 1300 333 362
Fax: (08) 7389 6567

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Executive Summary

Initiation of a high explosive from a single point produces a curved detonation wave propagating through the explosive charge. However, it is often desirable to produce a straight line initiation of the charge. This can be used to generate specific charge effects, reduce complexity of the analysis or reduce the problem to two dimensions for comparison with numerical modelling.

An explosive line wave generator can be used to produce line initiation. Two types of line wave generators were constructed and assessed using a Cordin high speed camera to directly image the shape and propagation of the detonation wave, specifically looking at the degree of wave curvature.

The first design, a perforated triangle, uses a triangle of sheet explosive with a regular pattern of holes cut into the explosive to give equal detonation wave path lengths from the initiation point at the triangle apex to the base. This design was not suitable for use with Primasheet 2000 explosive using an available hole template due to critical diameter issues, however, the concept functioned correctly using Primasheet 1000. The resulting detonation wave at the base still had some remaining curvature and charge preparation was time consuming.

The second design, an explosive lens, uses two explosives with different detonation velocities to modify the shape of the detonation wave and to remove the wave curvature. This produced a much flatter detonation wave, which could easily be fine-tuned further by a simple adjustment to the charge geometry, and was much simpler to construct.

In addition to a visual assessment of the wave curvature from the high speed camera images, the explosive lens design was also evaluated using piezoelectric pins positioned along the output end of the lens. The pin timings confirmed the correct functioning of the charge to produce a detonation wave with an acceptable level of curvature.

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Glossary

DSTO	Defence Science and Technology Organisation
EBW	Explosive Bridgewire
HEFC	High Explosive Firing Complex
PETN	Pentaerythritol Tetranitrate
RDX	Research Department Explosive
VoD	Velocity of Detonation

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1. Introduction

Initiation of a high explosive from a single point, such as when using a detonator, results in a curved detonation wave propagating through the explosive charge. However, in weapons research applications it is often desirable to produce straight line initiation of an explosive charge to produce specific explosive charge effects. This technique is also useful in reducing a problem to two dimensions, to simplify the problem, and for comparison with numerical modelling. An extension of this is plane wave initiation where an area of the explosive is simultaneously initiated, reducing the problem and analysis to one-dimension.

This report assesses several different types of explosive line wave generator, specifically looking at the resulting curvature in the detonation wave using high speed video to image the wave shape and propagation. This work was conducted to confirm correct line initiation of a main explosive charge.

2. Experimental Setup

The tests were conducted in Chamber 2 of DSTO's High Explosive Firing Complex (HEFC). The various explosive line wave generators were taped vertically on a supporting board and the detonation wave propagation imaged directly using a Cordin digital high speed camera (model 550). The basic experimental setup is shown in Figure 1. The Cordin is a rotating mirror CCD camera. It generates 62 frames of 1 megapixel resolution monochrome images at a framing rate of up to 4 million frames per second using a helium driven gas turbine. For the tests conducted here, the camera was run at either 1 or 2 million frames per second, giving either 62 or 31 microseconds duration of image data acquisition, respectively.

The explosive line wave generator charges were constructed from Primasheet explosive. Two different types of Primasheet were used for the tests: Primasheet 1000, a PETN based explosive, with a Velocity of Detonation (VoD) of 7.1 km/s; and Primasheet 2000, a faster, more powerful RDX based explosive with a VoD of 8.2 km/s. The charges were initiated with an Explosive Bridge-Wire (EBW) detonator, type RP80. The Primasheet 1000 is detonator sensitive, however, the Primasheet 2000 required a small booster constructed from Primasheet 1000 for initiation.

Figure 1 - Experimental setup for imaging the explosive line wave generator charges (the line wave generator is attached to the front of the wooden board).

3. Line Wave Generators

There are several different designs available in the literature for constructing an explosive line wave generator [1, 2]. These are:

(i) Perforated Triangle – equilateral triangle with round holes cut into the sheet explosive to give equal path lengths to a detonation wave propagating down from the triangle apex to the base.

(ii) Explosive lens – combination of different detonation velocity explosives to modify the shape of the detonation wave.

(iii) Explosive Fibres or Strips – Equal length strips propagating the detonation wave from a single point to multiple points simultaneously forming a line.

The first two designs are assessed here and the third is mentioned for completeness.

3.1 Perforated Triangle

The perforated triangle explosive line wave generator is shown in Figure 2 (left). The charge was constructed from sheet explosive using an aluminium template as shown in Figure 2 (right), with a cork borer to cut the holes. The triangle is equilateral and the pattern of holes produces a condition where the explosive path length is the same from the triangle apex to any point along the base. The detonation wave bifurcates as it propagates down around each hole to arrive simultaneously and recombine at the base. This produces a scalloped shape to the detonation wave, where the degree of scalloping is influenced by the size of the holes. The perforated triangle line wave generator requires significant time to construct. The template shown in Figure 2 (right) has sides approximately 250 mm in length, so to produce a line wave of this width requires a large number of holes to be cut.

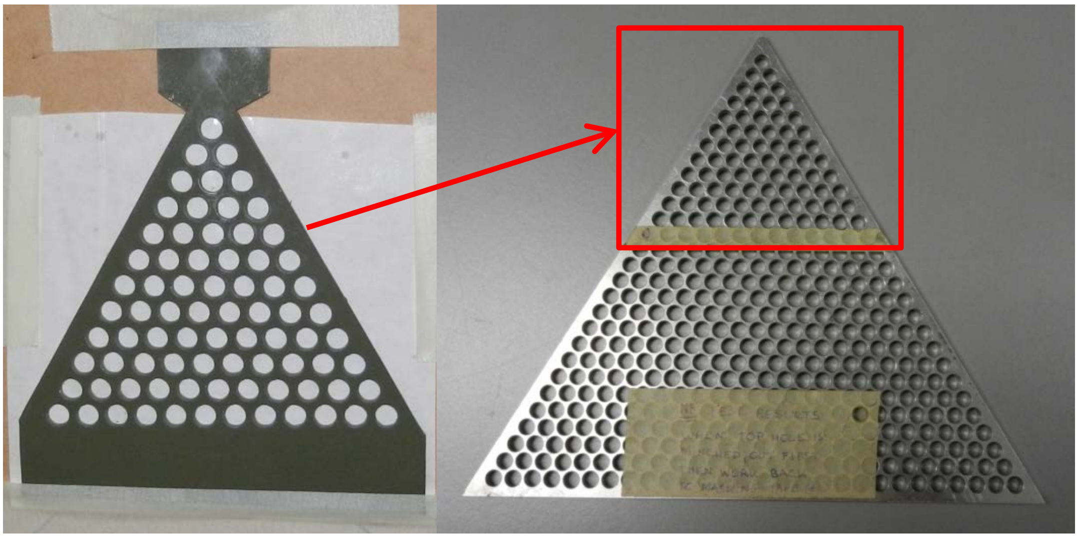

Figure 2 - Perforated triangle line wave generator cut from sheet explosive (left); and the template used for the charge construction (right), where only the top part of the template has been used for the charge on the left.

The perforated triangle line wave generator design was tested using both Primasheet 1000 and 2000 sheet explosive. The results from these tests are presented in the following sub-sections.

3.1.1 Primasheet 2000 Perforated Triangle

The Primasheet 2000 perforated triangle is shown in Figure 2 (left). This was cut from 3 mm thick explosive using only the top section of the template to give a triangle with side length of 125 mm. The charge was initiated with a booster constructed from Primasheet 1000. The booster was placed against the tab at the top of the triangle apex, on the reverse side to limit flash exposure to the camera. The Cordin camera was run at 2 million frames per second (0.5 μs between frames) and the images of the detonation wave propagation are shown in Figures 3-5.

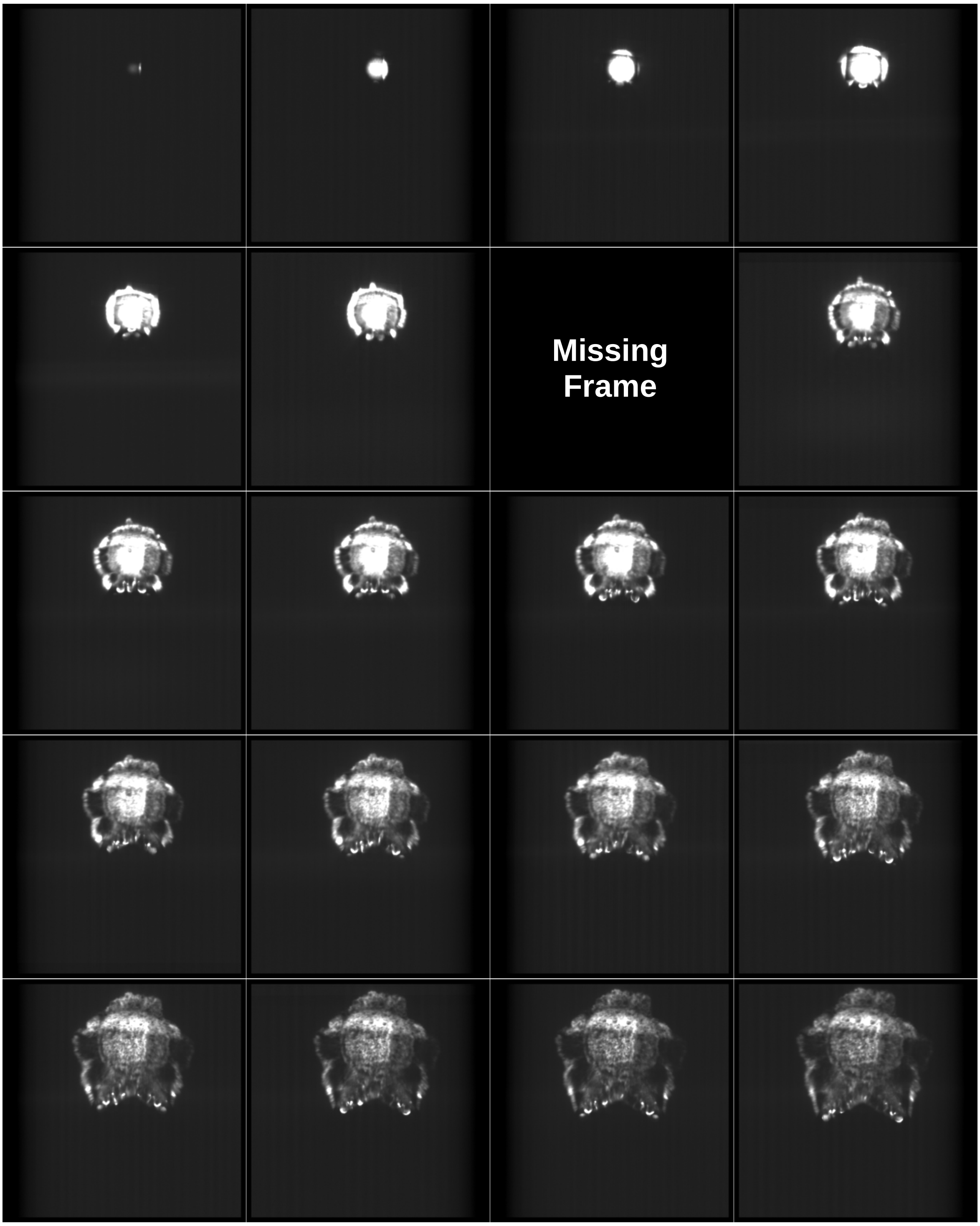

Figure 3 - High speed camera images (0.5 μs between frames, left to right and down the page) for the Primasheet 2000 perforated triangle line wave generator. Initiation occurred at the top of the frame and the images show the detonation front moving down the line wave generator.

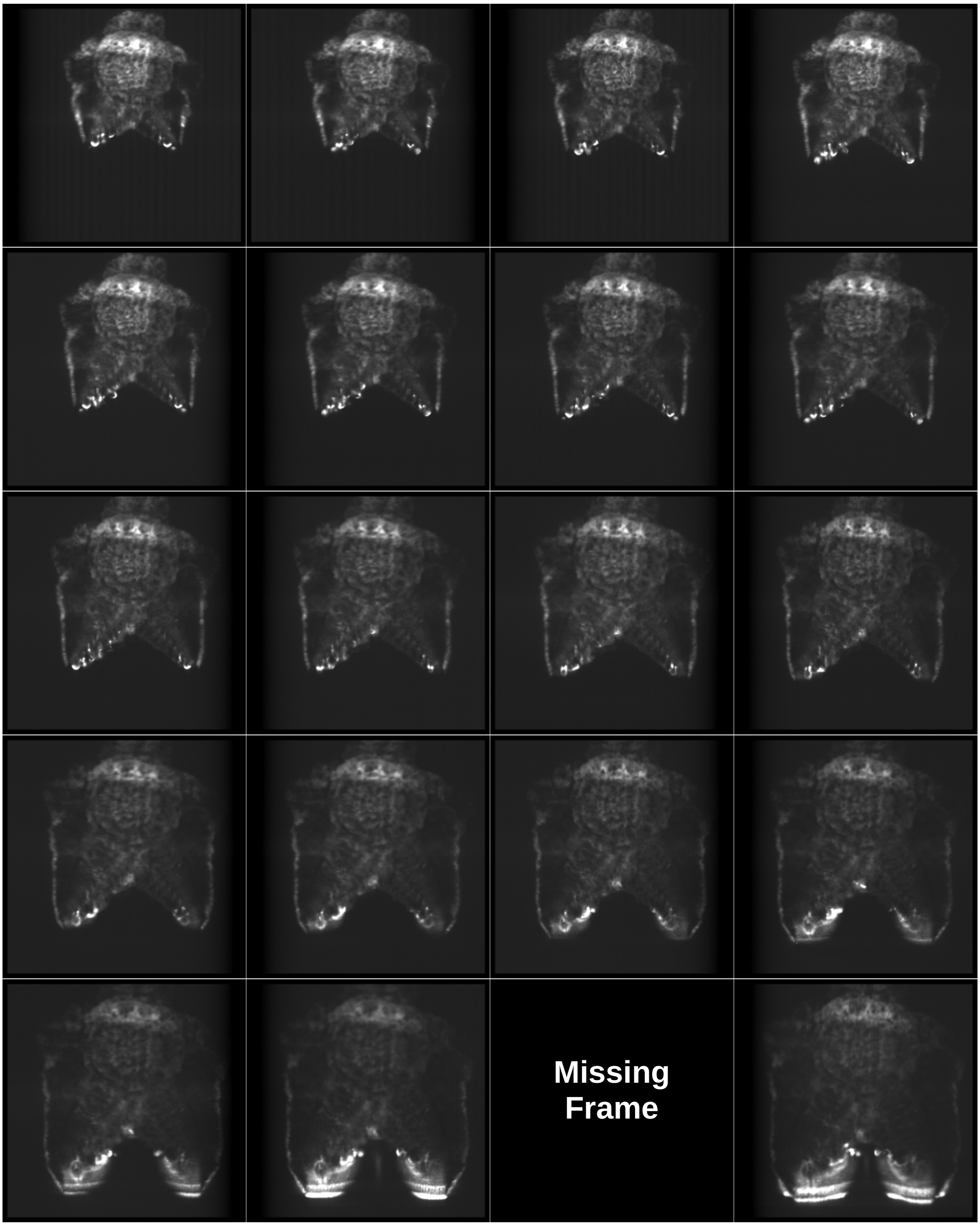

Figure 4 – Continuation of Figure 3 showing the high speed camera images of the detonation wave propagation for the Primasheet 2000 perforated triangle line wave generator.

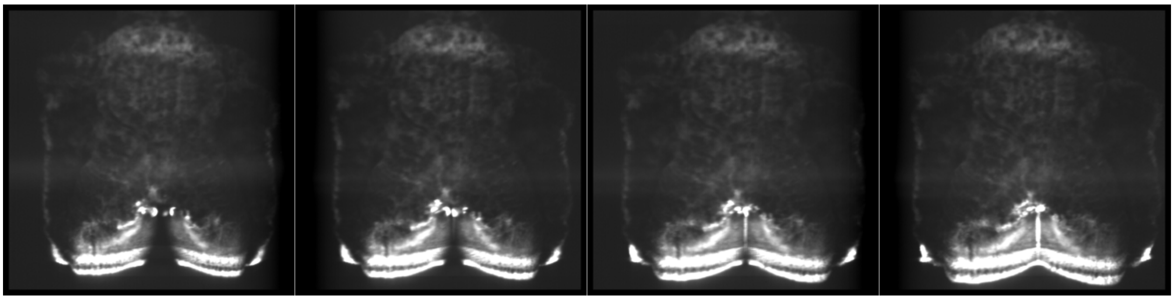

Figure 5 – Continuation of Figure 4 showing the high speed camera images of the detonation wave propagation for the Primasheet 2000 perforated triangle line wave generator.

The images in Figures 3-5 show that the detonation wave is well supported down the sides of the triangle where there is a greater width of explosive, however, there is a clear failure to propagate around the holes and down the centre. This indicates that the spacing between holes may be too close for the Primasheet 2000 given its critical diameter. At the bottom, the detonation waves from the sides propagate inwards causing a collision at the centre and associated jetting (Figure 5). Thus this represents a failed attempt at line wave generation in the explosive.

3.1.2 Primasheet 1000 Perforated Triangle

Primasheet 1000 has a smaller critical diameter compared to the Primasheet 2000. Several tests were conducted using Primasheet 1000 for the same perforated triangle design. The initial test functioned correctly, however, it did show some curvature with the detonation wave propagating faster in the centre compared with the sides. This test was repeated with steel confining strips added to the sides. It was anticipated that the confinement would help to increase the detonation velocity down the sides and reduce the curvature. The confinement slightly improved the functioning and so a larger triangle, with 240 mm sides was constructed as shown in Figure 6. Note the significant number of holes required for this charge.

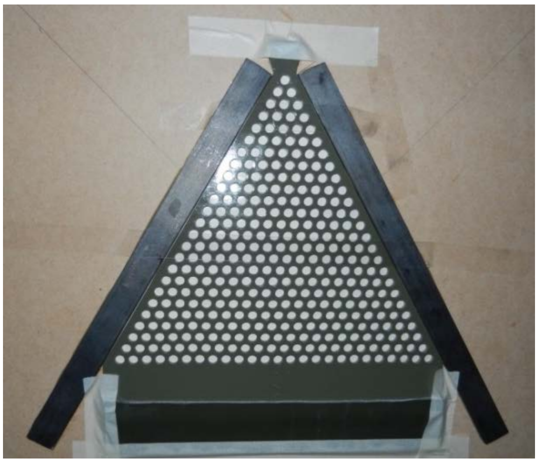

Figure 6 - Perforated triangle explosive line wave generator constructed using Primasheet 1000, 240 mm sides, with steel strips on the sides for confinement.

The charge, as shown in Figure 6, was constructed from 3 mm thick Primasheet 1000 explosive and initiated at the top of the apex. The detonator was supported by 2 annular pieces cut from Primasheet 1000 and placed against the tab from the rear. The steel strips were 20 x 5 mm in cross-section. The Cordin camera was run at 1 million frames per second (1 μs between frames). The images of the detonation wave propagation are shown below in Figures 7-9.

Figure 7 - High speed camera images (1 μs between frames, left to right and down the page) for the Primasheet 1000 perforated triangle line wave generator. Initiation occurred at the top of the frame and images show the detonation front moving down the line wave generator.

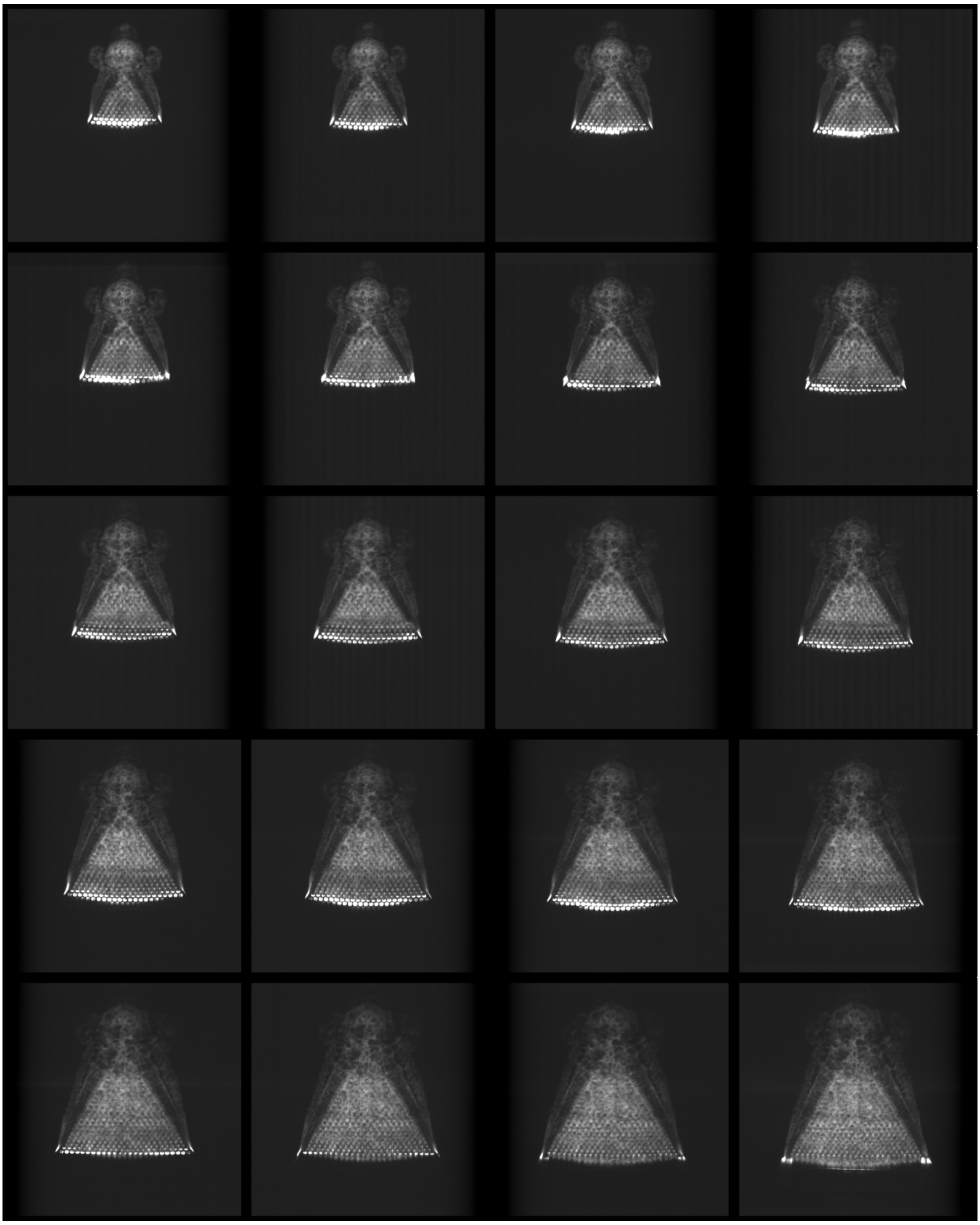

Figure 8 – Continuation of Figure 7 showing the high speed camera images of the detonation wave propagation for the Primasheet 1000 perforated triangle line wave generator.

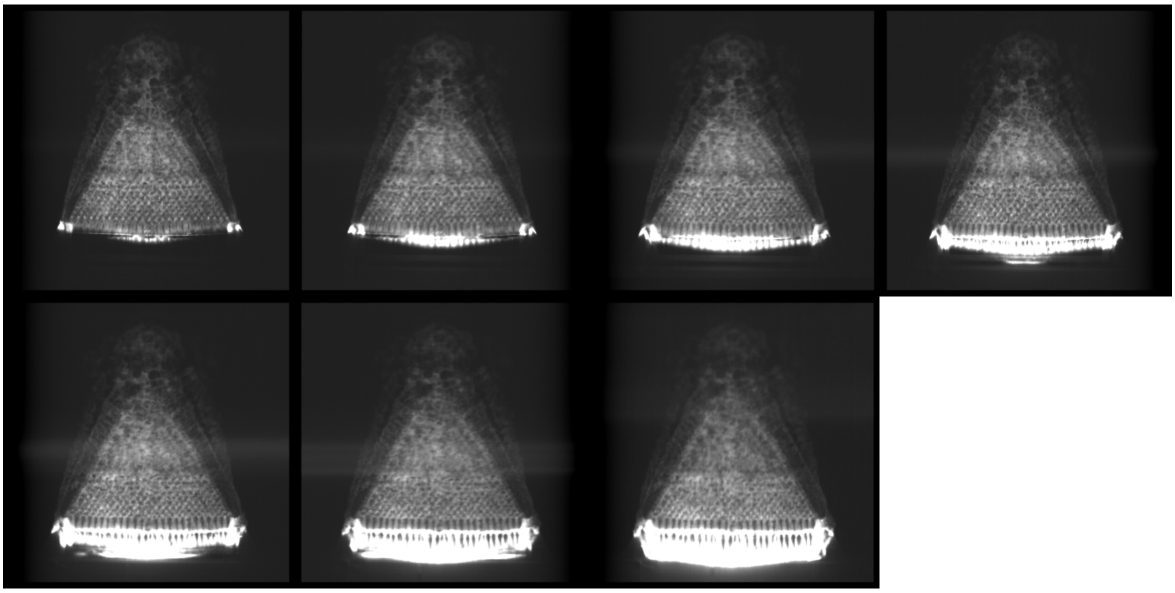

Figure 9 – Continuation of Figure 8 showing the high speed camera images of the detonation wave propagation for the Primasheet 1000 perforated triangle line wave generator

The images in Figures 7-9 show the propagation of the detonation wave around the holes and successful functioning of the line wave generator. The resulting detonation wave at the bottom has some curvature where the propagation is slightly faster through the centre. This curvature cannot easily be corrected with this design, without adjusting the size and spacing of the holes and constructing a new template.

3.2 Explosive Lens

The explosive lens line wave generator is shown in Figure 10. It uses two different speed explosives to remove the curvature from the detonation wave and produce a straight line wave. The faster explosive is placed along the longer path length as strips down the sides and the slower explosive forms the remainder of the triangle. The apex angle of the triangle is determined by the ratio of the two explosive detonation velocities, where the half angle, theta, is given by $\mathrm{Cos}(\theta) = V_1/V_2$. Thus for the Primasheet 1000 and 2000 combination, the apex half angle is 30 degrees resulting in an equilateral triangle.

The explosive lens concept for line wave generation can easily be extended to produce a plane wave generator, where the triangle becomes a cone and the two explosive parts are manufactured by casting and/or machining the explosive.

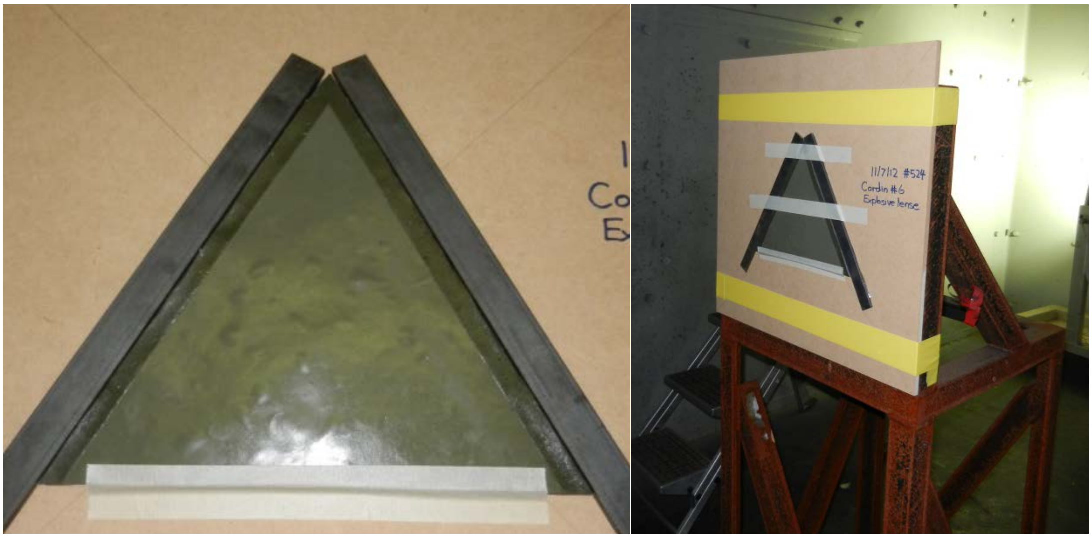

Figure 10 - Explosive lens line wave generator (left) constructed from Primasheet 1000 (light green triangle) and Primasheet 2000 (dark green strips) with steel confinement on the sides; and setup for firing in the chamber (right).

The charge was constructed from 3 mm thick sheet explosive and initiated at the top of the triangle apex from the rear. The triangle has 240 mm side lengths and 20 x 5 mm steel strips for confinement on the sides. The Cordin camera was run at 1 million frames per second (1 μs between frames) and the images of the detonation wave propagation are shown in Figures 11-12.

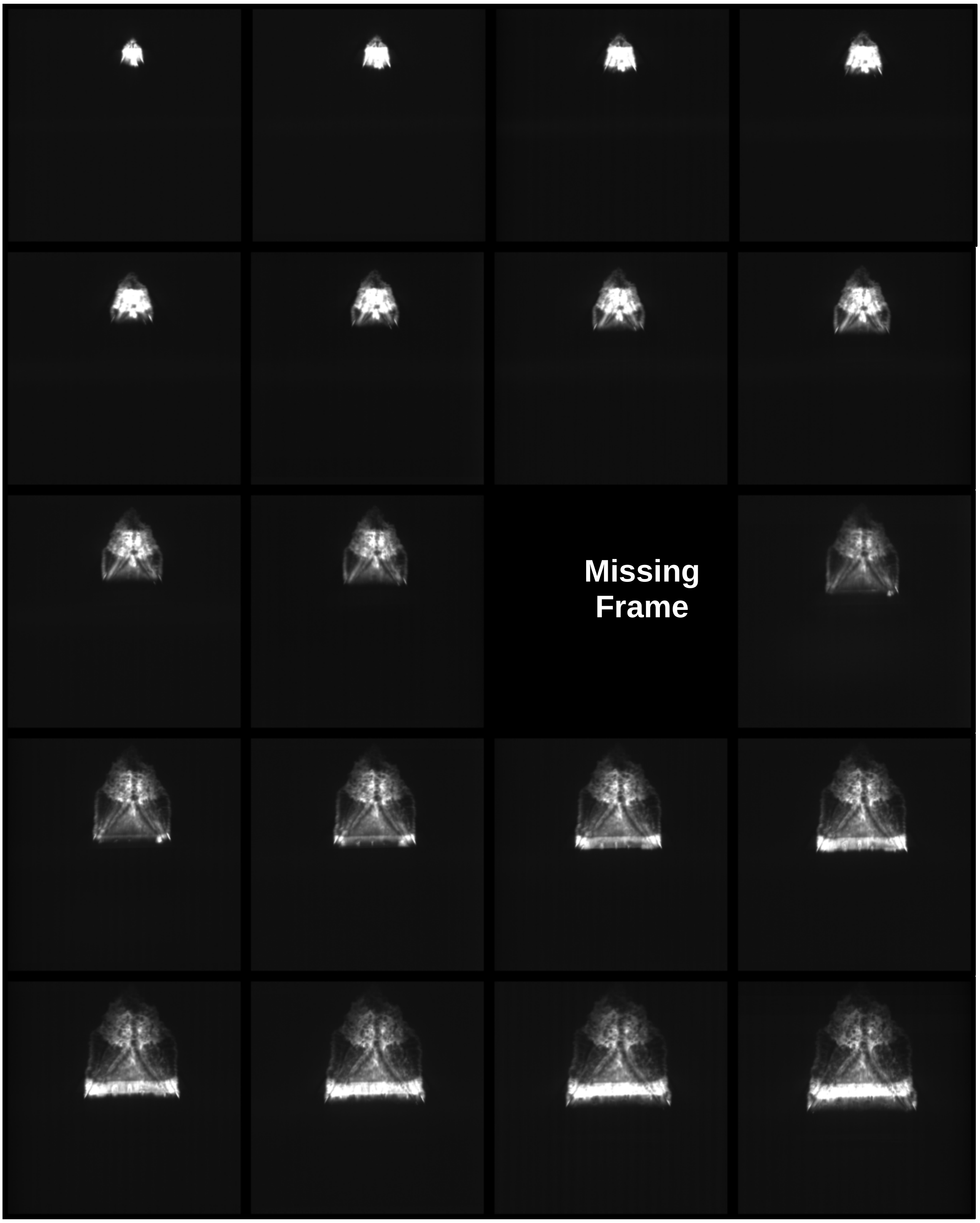

Figure 11 - High speed camera images (1 µs between frames, left to right and down the page) for the explosive lens line wave generator, constructed from Primasheet 1000 and 2000. Initiation occurred at the top of the frame and the images show the detonation front moving down the explosive lens

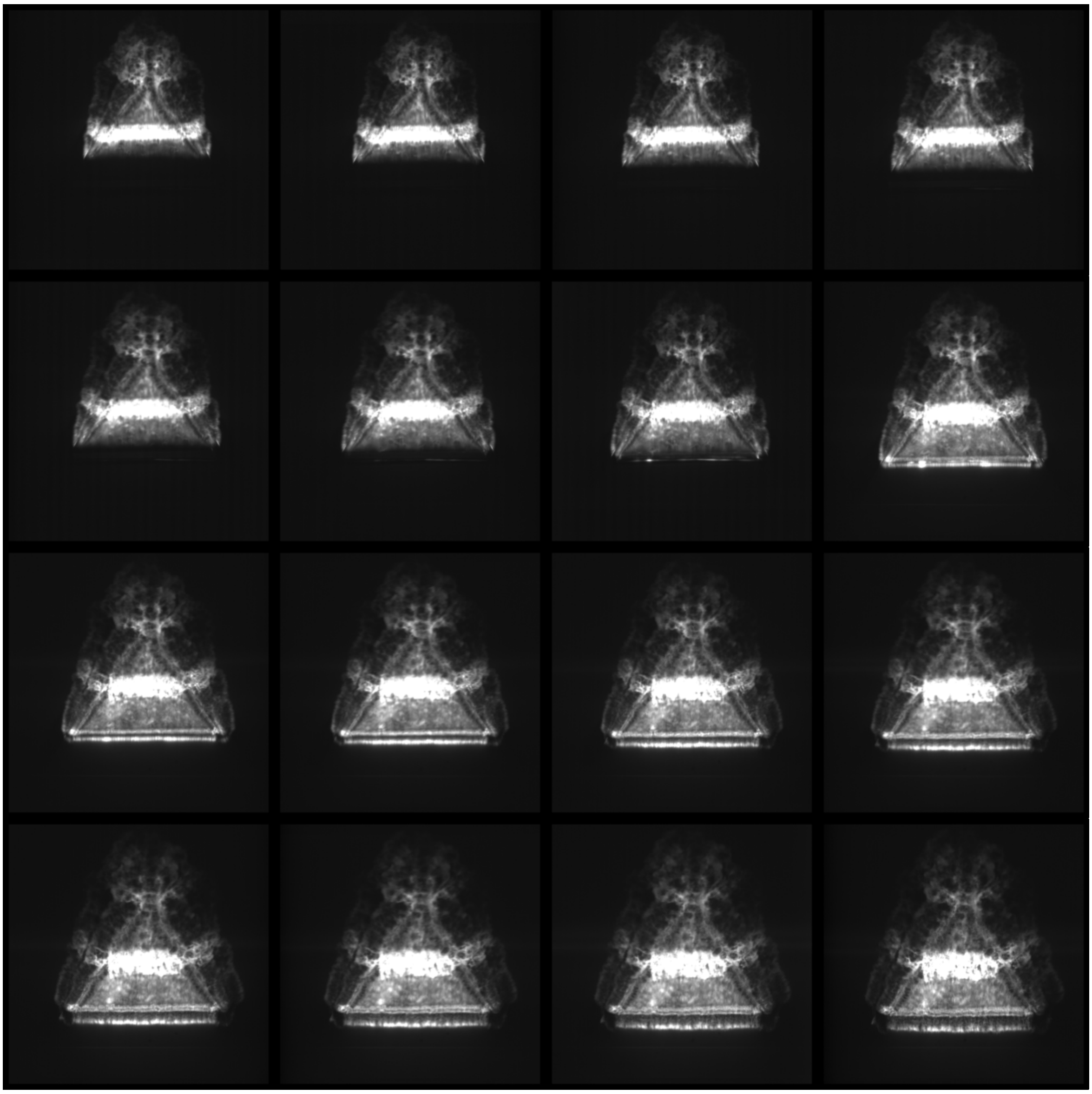

Figure 12 – Continuation of Figure 11 showing the high speed camera images of the detonation wave propagation for the explosive lens line wave generator.

The images in Figures 11-12 show the successful functioning of the explosive lens. The linearity of the resulting detonation wave at the bottom of the charge appears very good. There is still some slight curvature in the wave where it is faster in the centre, however, it appears significantly flatter than that achieved with the perforated triangle design. The explosive lens design also has the advantage that it can be fine-tuned to remove any remaining curvature by simply adjusting the apex angle of the triangle.

3.2.1 Piezopin Assessment of Wave Planarity

The explosive lens design was subsequently used for line initiation of a main charge. Piezo-electric pins were used to monitor the planarity of the detonation wave in these tests. Three pins (Dynasen model CA-1135) were positioned at the base of the 240 mm wide line wave generator at the centre (Pin 2) and +/- 90 mm (Pins 1& 3) to evaluate the planarity over 180 mm. The pins contain a piezoelectric material which produces a charge when compressed by the pressure of the detonation wave. This transient charge can then be recorded on an oscilloscope and the simultaneity of the signals from the three pins indicates planarity of the detonation wave. The timings of the pin signals for two tests are presented in Table 1.

Table 1 - Piezopin timings for the explosive lens line wave generator

	Pin 1 (-90 mm)	Pin 2 (centre)	Pin 3 (+90 mm)
Test #1	-	22.6µs	24.8 µs
Test #2	20.8 µs	19.4 µs	19.8 µs

For Test #1 the time difference between the centre and side pin (Pin 1 failed to function in this test) was 2.2 µs which corresponds to a curvature in the detonation wave of approximately 16 mm. The wave curvature was better in Test #2 with a maximum time difference between the centre and side pins of 1.4 µs giving a curvature of approximately 10 mm. In both cases the detonation wave arrived first at the centre (Pin 2) giving a convex profile to the wave. This level of curvature was acceptable for these tests, however, it is believed it could be reduced further by slightly decreasing the apex angle of the explosive lens.

4. Conclusions

Two different designs for an explosive line wave generator charge were constructed and tested, with the level of curvature in the resulting detonation wave imaged directly by high speed video.

The perforated triangle design was not suitable for use with Primasheet 2000 sheet explosive using the available template. For the current tests the hole spacing was found to be too small for the critical diameter of this explosive and the charge failed to sustain a detonation around the holes and down the centre of the charge. Primasheet 1000, with a smaller critical diameter, produced a correctly functioning line wave generator; however, the resulting detonation wave still displayed some curvature being faster in the centre section. By adding confinement to the sides and therefore increasing the detonation velocity in those regions, a slight reduction in curvature was achieved. A disadvantage of this design is the difficulty to fine tune and correct any remaining curvature, without constructing a new template with new hole size and inter-hole spacing. The perforated triangle design is also time consuming to construct the charge, as the number of holes increases as the line width increases.

The explosive lens design utilised two different speed explosives, Primasheet 1000 and 2000, with an apex angle of 60 degrees for the triangle. This charge design was much simpler to construct and produced a reasonably flat detonation line output. This design was used on a donor main charge to evaluate the line wave initiation. The curvature was monitored with piezoelectric pins which showed acceptable wave planarity of <16 mm deviation. The detonation wave was consistently slightly faster through the centre, which could be corrected by slightly reducing the apex angle.

5. References

[1] Zukas, J. A. and Walters, W. P., Explosive Effects and Applications, Springer-Verlag New York, 2003.
[2] Meyers, M. A., Dynamic Behaviour of Materials, John Wiley & Sons, 1994.

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19. ABSTRACT

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